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TARGET IDENTIFICATION PERFORMANCE: THE EFFECTS OF DISPLAY RESOLUTION AND TARGET RANGE

Jeffrey H. Lukas
Lynn C. Oatman

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An experiment was conducted to examine the effects of display resolution and target range on the ability of soldiers to identify tanks presented on a display monitor. Subjects learned to identify 24 images consisting of four tanks at three orientations and at two ranges. Subjects then identified targets using five levels of resolution produced by low-pass spatially filtering the images. The modulation transfer function area (MTFA) metric was calculated to be 9.1, 4.8, 3.6, 2.4, and 1.3 for the five levels of resolution. Subjects' visual capabilities were tested using the Contrast Sensitivity Function (CSF) Test; however, individual differences in the CSF did not correlate with target identification performance. Results indicated that target identification performance depended on the interaction of display resolution and target range. With near targets, loss of resolution had little effect on the percentage of targets identified or the response times until the MTFA fell below 2.4, whereas with distant targets, loss of resolution always degraded performance. These results indicate that operators of indirect viewing devices do not require high resolution images as long as the targets are large and high contrast.

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CONTENTS

EXECUTIVE SUMMARY

An important design consideration for an indirect viewing device such as an automatic target recognition (ATR) system concerns how much resolution is necessary for the operator to identify a target. Previously, resolution has often been specified in terms of television (TV) raster lines. However, TV raster lines do not uniquely determine resolution nor are they particularly relevant to human visual processing. Resolution was approached in terms of spatial frequencies since human form recognition is based on spatial frequency analysis of an object. Scenes containing target tanks were digitally filtered to remove the high spatial frequencies and to produce low resolution, blurry images. Optimal soldier-machine performance also requires selection of operators who have the best visual capabilities. Since previous research indicated that pilots who were able to detect spatial frequencies at lower contrasts detected aircraft quicker and at greater ranges, another purpose was to determine if soldiers' contrast sensitivity correlated with their target identification performance.

Visual acuity was tested using a Snellen chart, and contrast sensitivity was assessed using Ginsburg's Contrast Sensitivity Function (CSF) Test as well as with a computer-generated CSF Test. Subjects were trained to make error-free identification of 24 images presented on a display monitor. The images consisted of U.S., British, Russian, and Israeli tanks, each presented in the front, side, and rear orientations and at two ranges: 60 and 120 meters. Subjects were required to identify as quickly as possible a random sequence of these tanks using five levels of resolution produced by low-pass filtering each image at 128, 64, 48, 32, and 16 Hz (cycles per display width) to remove the high spatial frequencies. Resolution was quantified using the modulation transfer function area (MTFA) defined as the area between the curve representing the ability of the equipment to resolve spatial frequencies and the curve relating the human's ability to perceive spatial frequencies. The MTFAs for the five resolution levels were calculated to be 9.1 for the 128-Hz low-pass filter, 4.8 for the 64-Hz, 3.6 for the 48-Hz, 2.4 for the 32-Hz, and 1.3 for the 16-Hz low-pass filter. All but the highest MTFA were below the U.S. standard of five for monochrome cathode ray tubes (Human Factors Society, 1988). Two measures of performance were examined using analysis of variance (ANOVA), the percent targets identified and the response times (RTs). In addition, each subject's contrast sensitivity was correlated with his target identification performance.

Both performance measures produced a significant Range x Resolution interaction indicating that performance was quite different for the near and far targets. For the near targets, there was no significant effect on performance when subjects observed the 128-, 64-, and 48-Hz low-pass filtered images, and even with the 32-Hz filtered images, subjects still correctly identified more than 92% of the targets. With the highest resolution images, subjects identified the far targets as accurately as the near targets, although the RTs were slightly longer. However, when resolution was degraded, performance was always significantly worse for the far targets, and each loss of resolution produced a corresponding degradation in performance. Performance was best with the side orientation and the Israeli tank. Surprisingly, soldiers had particular difficulty identifying the U.S. tank especially at the far range using reduced resolution. Neither measure of the CSF for individual subjects correlated with performance. However, a significant negative correlation between the performance measures indicated that the fastest subjects were also the most accurate.

Based on these results, it was concluded that a high resolution image is not required for identifying targets using an ATR, provided the remote sensor can get close to the targets. If the sensor cannot get close, operators will require a high resolution system to correctly identify friendly and enemy tanks. Although the CSF did not correlate with target identification performance with large, high contrast targets, this measure of visual performance may predict detection performance with small, low contrast targets.

TARGET IDENTIFICATION PERFORMANCE: THE EFFECTS OF DISPLAY RESOLUTION AND TARGET RANGE

INTRODUCTION

The U.S. Army is currently interested in developing remotely piloted vehicles and automatic target recognition (ATR) systems for remotely identifying enemy targets. The capability of performing a mission from a remote position with visual information presented on a display monitor, has the potential advantage of enhanced performance coupled with reduced personal risk. Superior visual capabilities are relevant to virtually all missions, and rapid target identification remains the primary problem facing weapon system operators (Doll, 1991). A crucial design consideration for any indirect viewing device concerns the resolution required for the operator to correctly detect, recognize, and identify targets. In the visual sciences, resolution refers to the task of visually discriminating elements of a pattern such as a row of alternating light and dark bars. The elements are said to be resolved when the observer can just distinguish the separate bars (Riggs, 1965). Among system designers, resolution is often considered in terms of some physical aspect of the equipment such as television (TV) raster lines, spot size, or horizontal bandwidth (or pixels and shades of gray in digital systems). The ability of the equipment to resolve fine details depends partly on the number of raster lines or pixels.

Much is known about resolution in terms of TV raster lines and target detection, recognition, and identification (e.g., Erickson, 1978; Goble, Williams, Pratt, Wald, Rubin, & Hanson, 1980; Meister, 1984). The number of raster lines required across the target generally increases as the level of discrimination goes from detection to recognition to identification. Johnson (1958) found that two TV lines across the smallest dimension of the target are required for detection, and eight TV lines are required for recognition. Ratches, Lawson, Opert, Bergemann, Cassidy, and Swenson (1975) reported that the 50% probability of detection and recognition using thermal viewing systems required two and eight TV lines, respectively. To achieve 90% probability, three TV lines were required for detection, and 14 TV lines were required for recognition. Approximately 10 to 12 scan lines are required to identify most high contrast targets (large targets required 20 scan lines). Further increases in resolution produced little improvement in performance (Erickson, 1978).

Although research has often focused on TV raster lines and performance, specification of TV lines does not, in and of itself, uniquely determine the system's resolving power (Meister, 1984). In fact, Meister does not include raster lines as one of the seven factors affecting display resolution (frame rate, contrast ratio, registration, phosphor, symbol characteristics, bandwidth, display brightness, and viewing geometry). Biberman (1973, 1974) provides a penetrating and highly recommended discussion of the raster line-resolution fallacy and demonstrates that a system with more raster lines does not necessarily improve either image quality or system resolution. Finally, TV raster lines is not a particularly relevant factor for human visual processing. From a human factors perspective, consideration of resolution in terms of spatial frequencies is more appropriate. The human visual system analyzes any object in terms of the fundamental spatial frequencies comprising that object as part of the overall process of form perception (DeValois & DeValois, 1988; Ginsburg, Cannon, & Nelson, 1980; Ginsburg, 1981). Just as a complex sound can be decomposed into a series of pure sine waves or frequencies using Fourier analysis, a complex object or scene can be decomposed into a series of sine wave gratings or spatial frequencies. High spatial frequencies correspond to sharp edges and fine detail, while low spatial frequencies determine the overall shape or form of the image (Howard, 1986; Oatman, Holly, & Birkmire, 1990).

The purpose of this study was to determine the effects of resolution on target identification performance using an indirect viewing device. Resolution was varied by digitally filtering scenes containing target tanks to remove the high spatial frequencies. Subjects were required to identify targets using five levels of resolution ranging from unfiltered, high resolution, sharp images to filtered, low resolution, blurry images. Resolution was quantified using the modulation transfer function area (MTFA) metric which has been adopted in the USA as an image quality standard (Feng, Ostberg, & Lindstrom, 1990; Human Factors Society, 1988). Essentially, this metric measures the area between the modulation transfer function (MTF), which represents the ability of the equipment to resolve spatial frequencies, and the contrast sensitivity function (CSF), which psychophysically measures the threshold contrast necessary for humans to perceive spatial frequencies (see Figure 1). The MTFA has the important distinction of indexing the spatial frequency information transmitted by the display that can be perceived by the human operator. As such, it is a better measure than those that fail to adjust for the operator's visual requirements (Goble et al., 1980). In addition, the MTFA has been shown to correlate with target acquisition performance (Snyder, 1976; Gutmann, Snyder, Farley, & Evans, 1979; Snyder, Keesee, Beaman, & Aschensach, 1974). The image quality of any analog or digital system can be objectively evaluated using the MTFA and directly compared to any other system or standard. The U.S. standard (Human Factors Society, 1988) states that the MTFA was chosen as the metric to quantify resolution and that the MTFA for monochrome cathode ray tubes (CRTs) should be at least 5. The MTFA of 5 "should be treated as a threshold for adequate visual performance..." (p. 18). Finally, design engineers developing an indirect viewing system could estimate the expected target identification performance based on the system's MTFA and could determine whether more resolution is necessary to achieve a required level of performance.

Achieving optimal performance in any soldier-machine system depends on designing the equipment for efficient and effective use by the operator. Equally essential is the selection of operators who are able to use the equipment to its maximum capability. Since performance with any indirect viewing system depends heavily on the operator's visual capabilities, a second goal is to determine if the CSF, a direct and comprehensive measure of visual functioning, correlates with target identification performance. If it does, the CSF may provide a valuable screening device to select operators who will maximize system performance. A promising start in this direction has already begun. Ginsburg, Easterly, and Evans (1983) reported that Air Force pilots who were able to detect spatial frequencies at lower contrasts were also able to detect T39 aircraft at greater ranges and more quickly than were pilots with less contrast sensitivity. Based on these results, the authors concluded that "...contrast sensitivity may have predictive value for other operationally relevant visual tasks as well. Therefore, the selection of highly sensitive individuals for tasks requiring high visual capability may optimize the probability of success of visual target acquisition" (p. 272). If Ginsburg's conclusions are supported in the present study, measurement of contrast sensitivity may prove valuable as a screening device to select operators for indirect viewing devices, as well as an integral component in the assessment of image quality.

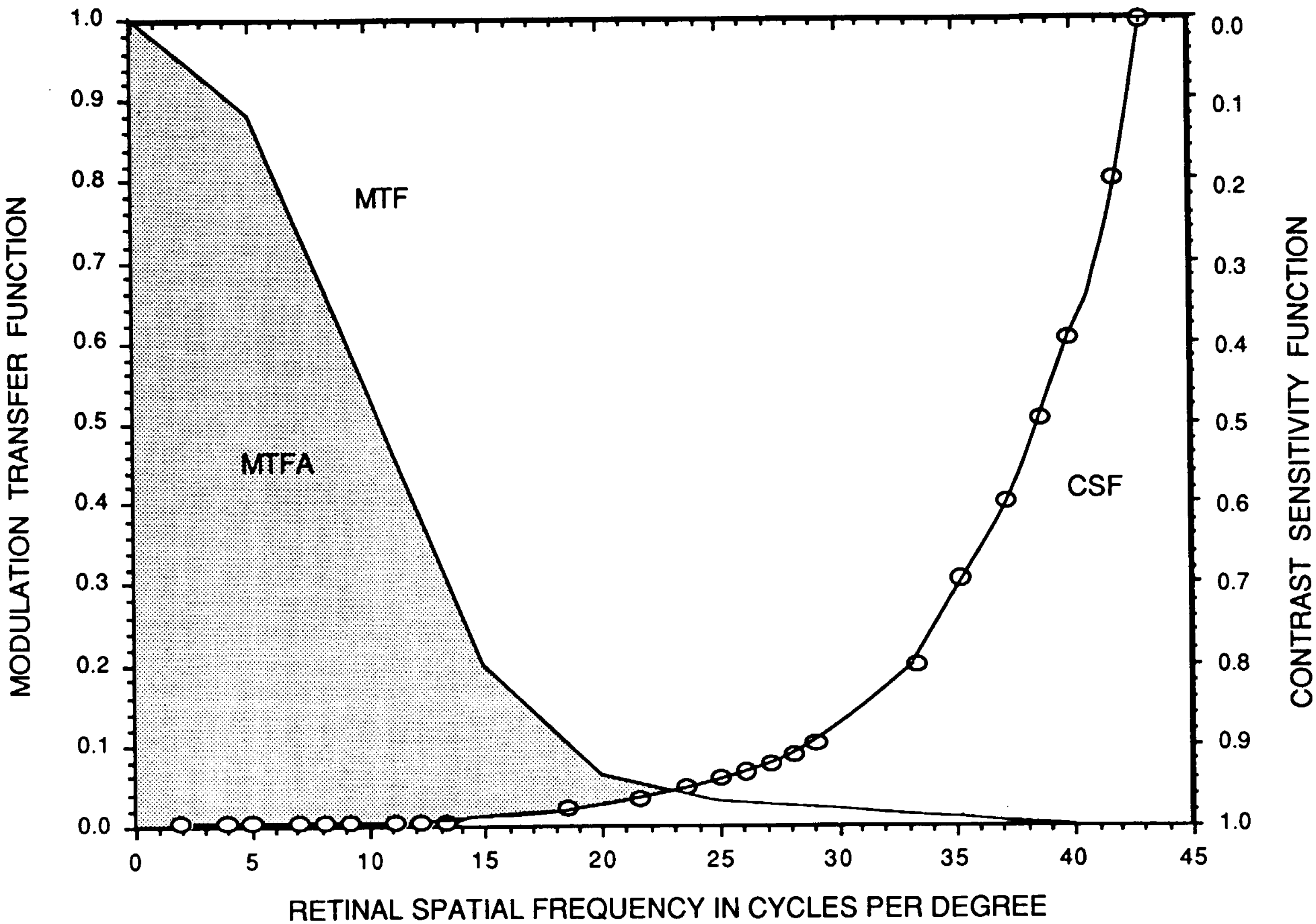

Figure 1. The modulation transfer function area (MTFA) metric for resolution.

OBJECTIVES

The objectives of this study were (a) to determine target identification performance as a function of system resolution as quantified by the MTFA, and (b) to determine if soldiers' sensitivity to low contrast spatial frequencies correlates with their target identification performance.

METHOD

Subjects

Twenty male soldiers stationed at Aberdeen Proving Ground, Maryland, volunteered to serve as subjects. Subjects ranged in age from 19 to 38 with a mean age of 25.0 years, and all subjects had far visual acuity of 20/20 or better (three had 20/20, 14 had 20/15, and three had 20/10 acuity). None were experiencing any visual problems at the time of testing. Subjects read and signed a volunteer consent form. Six different military occupational specialties (MOSs) were represented in this sample of subjects: 11B, 11M, 13B, 19E, 19K, and 88M.

Materials and Apparatus

Target images consisted of scale model tanks photographed in black and white at eye level in a flat, desert scene with mountains in the background. Twenty-four target images were prepared by Dr. Zwick at Letterman Army Institute of Research and loaned to the U.S. Army Human Engineering Laboratory (HEL) for this study. The images consisted of the U.S., British, Soviet, and Israeli tanks, each photographed from the front, side, and rear orientations and at two ranges, 60 and 120 meters. The tanks were placed unobscured in the center of the scene.

A digital image-processing system (Monroe & Zwick, 1984) was used to digitally filter the target images, as well as to control image presentation to the subjects and to record their response times (RTs). The system consisted of a computer with a black-and-white monitor and a 13-inch color monitor for presenting images to the subjects. The color monitor displayed monochrome images with a maximum resolution of 512 x 480 pixels. The luminance measured 135 candelas per square meter (cd/m^2) in the center of the blank screen. The computer was equipped with an input/output (I/O) board for recording subjects' RTs. The computer also had hardware and software necessary for collecting, storing, and digitally filtering images and presenting these images to the subject. The color monitor was placed on a table at eye level within a double-walled acoustical chamber. All other equipment was placed outside the chamber in the control room.

Target images were digitized with a resolution of 512 x 512 pixels and 255 shades of grey and stored on the computer's hard disk. Five levels of resolution were obtained using a digital filtering procedure. First, a fast Fourier transform (FFT) was used to transform each of the digital images into the frequency domain. The transformed images were then digitally filtered by applying a 10th order Butterworth low-pass filter to remove the high spatial frequencies in both the horizontal and vertical dimensions. Image resolution was degraded using low-pass filters with half-amplitude cutoff frequencies of 128, 64, 48, 32, and 16 Hz (cycles per display). Finally, the images were reconstituted without the spatial frequencies above the cutoff using an inverse FFT. Removing the high spatial frequencies from an image eliminated details and produced a low resolution, blurry image. The filtering procedure produced less than a 1% change in average pixel value (luminance) or contrast of the images. Luminance values of two regions on each image were sampled: the area of the dark tank treads on the sandy ground and the area of the dark mountains against the brighter sky. The final stimulus set consisted of 120 images (5 resolution levels x 2 ranges x 4 tanks x 3 orientations) stored in computer memory. The side orientation of the 60-meter targets viewed 1 meter from the screen formed a visual angle of $2.8^{\circ} \times 9.9^{\circ}$.

The MTFA was calculated separately for each of the low-pass filters based on the formulas for color CRTs (Infante, 1985). This was necessary even though the images were presented in black and white since the CRT was a color monitor. Based on an estimated spot size of 0.014 inch, the following MTFAs were calculated:

LOW-PASS FILTER	MTFA
128	9.1
64	4.8
48	3.6
32	2.4
16	1.3

Procedure

Subjects were told that the purpose of the experiment was to determine their ability to identify target tanks using various resolution levels to design indirect viewing devices such as ATRs. Subjects were informed that they would receive a letter of appreciation for their efforts. Subjects then signed a consent form. Information was collected about their age, MOS, and any known visual problems.

Vision Testing

Subjects viewed a Snellen chart binocularly from a distance of 20 feet and read the letters aloud to the experimenter. Visual acuity was recorded as the smallest line from which 7 of 10 letters could be correctly identified.

Contrast sensitivity was then assessed using two tests: (a) the Vistech VCTS 6500 CSF Test developed by Ginsburg, and (b) a computer-generated CSF Test. Subjects first completed the Vistech CSF Test. Subjects stood 10 feet from a chart containing photographic images of vertical sine wave bars at five spatial frequencies: 1.5, 3, 6, 12, and 18 cycles per degree (cpd). Each spatial frequency was in a separate row, and contrast decreased from left to right. Contrast was defined as (Lmax - Lmin)/(Lmax + Lmin) in which Lmax is the luminance of the peak of the sine wave, and Lmin is the luminance at the minimum. The subject read across each row indicating whether the bars were oriented up and down, to the right, or to the left. The experimenter recorded the responses and determined the lowest contrast correctly identified by the subject. These contrast values were translated into contrast sensitivity using a table provided by the manufacturer.

A second test of contrast sensitivity was then performed using the computer to generate a series of vertical sine wave bars and to vary their contrast. The subject sat in the double-walled acoustical chamber with his head stabilized using a chin and forehead rest 6.5 feet from the monitor. The computer presented vertical sine wave bars at six spatial frequencies: 1, 2, 4, 8, 16, and 24 cpd. Spatial frequencies were presented in ascending order with five trials at each frequency. Each trial began with a 2-second exposure of the target sine wave bars, followed by a blank screen for 3 seconds to minimize afterimages. The target bars were then presented at .004 contrast, the lowest contrast obtainable with 255 shades of grey (1/255 = .004). Contrast was gradually raised until the subject detected the target and pressed a response button held in his dominant hand. The subject was allowed three practice trials with this procedure and then completed the remaining 30 trials at his own pace. Contrast sensitivity was calculated for each spatial frequency as the reciprocal of the mean of the five threshold contrast values.

Training

The training procedure for target identification was conducted in the double-walled acoustical chamber and consisted of two phases. The subject was first familiarized with the 24 target stimuli (4 tanks x 3 orientations x 2 ranges) and then completed 10 learning trials. During familiarization, the subject sat 1 meter from the monitor and observed each target with the correct identification displayed on the screen. The experimenter pointed out obvious differences that could be used to identify the tanks. The near range, 60-meter targets were shown first, followed by the far range, 120-meter targets. Next, all four tanks were shown simultaneously at each orientation. Finally, the subject was allowed to view the 24 stimuli one at a time at his own pace. This completed the familiarization procedure.

The learning procedure consisted of 10 trials, each with a random order of the 24 target stimuli. For the first five trials, a fixation cross appeared in the center of the screen for 1 second, followed by a target presented for 5 seconds. The subject was instructed to press the response button as soon as he could identify the target, and then verbally state over a two-way intercom whether the target was a U.S., British, Soviet, or Israeli tank. The experimenter recorded each response. Responses taking more than 5 seconds were scored as errors. The experimenter verbally indicated the correct response following any incorrect identification. The target remained visible 4 seconds after the subject pressed the response button. At the conclusion of each trial, feedback was provided concerning how many targets were missed. Following a short break, the remaining five trials were completed in the same manner as the previous trials except that the target disappeared after the response button was pressed. Subjects were required to correctly identify all 24 targets in a trial before beginning the study. All subjects surpassed this criterion and performed perfectly at least two of the last three learning trials. This completed training.

Experiment

The experiment began following a short break. Ten experimental trials were split into two blocks of five trials separated by a break. During the experiment, no feedback was provided after an incorrect response or at the end of each trial. The same procedures were used as in the last five training trials. A fixation cross appeared on the screen for 1 second, followed by one of the 24 images which remained on for 5 seconds or until the subject pressed the response button. The screen blanked for 4 seconds and then the fixation cross reappeared, indicating another image would be presented. The order of images within each trial was randomized. Subjects were instructed to press the response button as soon as they could identify the target and to state whether the target was a U.S., British, Soviet, or Israeli tank. Subjects were informed that the images would range from sharp, high resolution to very blurry, low resolution and that each trial would be at a different resolution level. They were encouraged to guess if they were unsure of the target. Subjects were randomly assigned a subject number and received the five resolution levels within each block according to a counterbalanced experimental design. Subjects were given a break after five trials and were debriefed following completion of the last trial.

RESULTS

For the first objective, two measures of target identification performance were analyzed: (a) Percent correct identifications, the percent correct responses of the total possible valid responses; and (b) RT, the time between when the stimulus appeared on the monitor and when the subject pressed the response button. When the subject could not identify the target within the 5-second time limit, a 5-second value was entered as the RT.

For the second objective, subjects' contrast sensitivity for each spatial frequency was correlated using the Pearson's *r* statistic with the number of correct identifications and mean RTs using each of five resolution levels. Correlations were performed using contrast sensitivity scores obtained with the Ginsburg CSF Test as well as with the computer-generated CSF Test.

Training Performance

The familiarization procedure proved to be very effective. During the first training trial, subjects correctly identified 89% of the targets, and by trial 10, performance had risen to 99.8% correct identifications. Both the percent correct responses and RTs improved with training, with most of the improvement occurring during the first five trials. Three subjects achieved perfect performance during all 10 training trials. All subjects performed perfectly at least two of the last three trials. RTs also decreased 40% across trials from an average of 1.869 seconds during the first trial to 1.123 seconds during the last trial. Although every subject responded faster with practice, subjects varied considerably in their mean RTs, ranging from .598 to 2.559 seconds, with an average RT of 1.381 seconds. The best subject responded nearly four times faster than the slowest subject responded. In addition, a highly significant negative correlation was found between percent correct identifications and RTs ($r = -.811$, $p<.005$), indicating that subjects who responded faster also made fewer errors.

Percent Correct Identifications

Results from the 10 experimental trials were analyzed using a 5 (resolution levels) x 2 (range) factorial, repeated measures analysis of variance (ANOVA). The Tukey Honestly Significant Difference (HSD) Test was used for post hoc comparisons of significant effects. For this ANOVA, data were collapsed across targets, orientations, and repetitions. Repetition was not included in the ANOVA, since subjects correctly identified virtually the same number of targets for the two repetitions (1832 versus 1835). Performance with the individual targets and orientations were analyzed separately. Results from the ANOVA indicated that both the main effects for resolution, $F(4,76) = 334.74$, $p<.0001$, and range, $F(1,19) = 321.43$, $p<.0001$ were highly significant. With a loss in resolution produced by low-pass spatial filtering, fewer targets were identified. Increasing the range to the target also degraded performance. However, these main effects need to be interpreted cautiously in light of the significant Resolution x Range interaction, $F(4,76) = 30.24$, $p<.0001$ shown in Figure 2. These data are plotted versus the calculated MTFAs as well as the low-pass filters. Targets at the near range were correctly identified even when resolution was very degraded. No appreciable loss of performance occurred following low-pass filtering of 128, 64, or 48 Hz. Subjects correctly identified more than 98% of the targets. Some performance degradation occurred after 32-Hz low-pass filtering, but even then, 92% of the targets were still correctly identified. Note that the 64-, 48-, and 32-Hz low-pass filters produced MTFAs below the U.S. standard for monochrome CRTs. However, for the lowest resolution condition, performance fell to 42% correct identifications. Post hoc multiple comparisons (Tukey HSD) indicated that the mean for the lowest resolution condition differed significantly ($p<.01$) from the other four means which did not differ. These results suggest that the human operator does not require a high resolution system as long as the sensor can get reasonably close to the target.

For the far targets, subjects identified more than 98% of the targets using the highest resolution images, essentially the same percentage as found for the near targets. However, unlike results for the near targets, loss of high spatial frequencies degraded target identification performance for the far targets at all resolution levels. Following 16-Hz low-pass filtering, performance was at chance level (25%). In other words, subjects could have guessed and performed just as well as they did observing the degraded images.

Post hoc comparisons indicated that the means were all significantly different ($p<.01$) at each resolution level for the far targets. In addition, performance was significantly worse ($p<.01$) for the far targets than for the corresponding near targets for all resolution levels except the highest resolution level.

Response Times

RT data were collapsed across targets, orientations, and repetitions and cast into a 5 x 2 factorial, repeated measures ANOVA. The Tukey HSD Test was used for post hoc comparisons of significant effects. Since the data failed the Mauchly Sphericity Test, the degrees of freedom for the F tests were reduced based on the Box-Geisser-Greenhouse Index. The main effects for resolution, $F(1,19) = 395.58$, $p<.0001$, and range, $F(1,19) = 1125.40$, $p<.0001$, were highly significant. Decreasing resolution or increasing the range to the target produced an increase in the RT. Figure 3 presents the significant Resolution x Range interaction, $F(1,19) = 48.23$, $p<.0001$. As reported for the percent correct identifications, loss of resolution did not seriously degrade RTs for the near targets, with similar RTs for the 128-, 64-, and 48-Hz low-pass filtered images. However, RTs for the near targets increased with further loss in resolution produced by the 32- and 16-Hz filters. Post hoc comparisons indicated that the 32- and 16-Hz filters produced significantly ($p<.01$) longer RTs than did the higher resolution conditions.

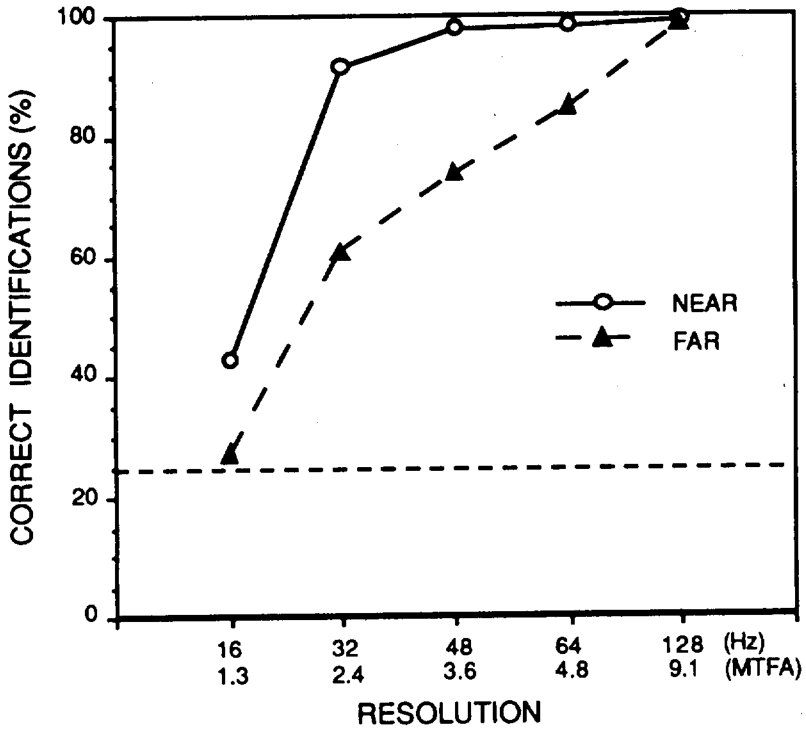

Figure 2. Mean percent correct identifications by range and by resolution.

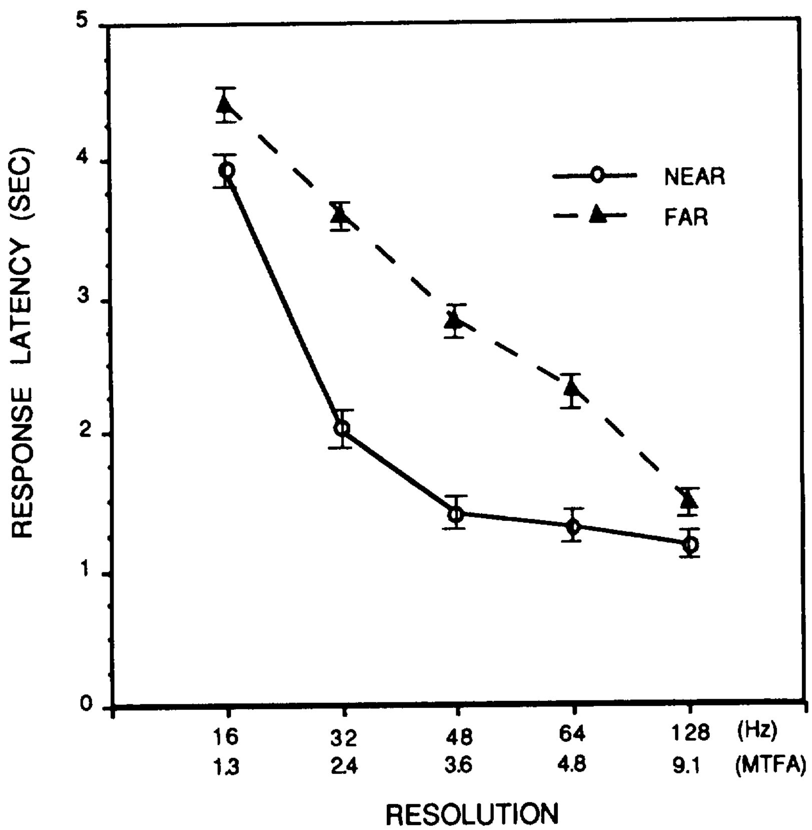

Figure 3. Mean response time by range and by resolution.

For the far targets, loss of resolution had a clear and consistent effect, with RTs becoming systematically longer as resolution decreased. Post hoc comparisons indicated that the means were all significantly different ($p<.01$). In addition, RTs for the far targets were longer at all resolution levels than the corresponding RTs for near targets. Again, the Tukey HSD Test indicated that the differences attributable to range were all significant ($p<.01$).

As found with the learning performance measures, there was a highly significant negative correlation between RTs and percent correct identifications (Pearson r = $-.853$, $p<.005$). Faster subjects correctly identified more targets than did slower subjects. For example, the fastest subject responded in an average of 1.95 seconds and also correctly identified 85% of the targets, the best percentage of any subject. Conversely, the slowest subject took 1.4 seconds longer to respond and detected 25% fewer targets.

Orientation and Target Analyses

Results of the orientation analysis in terms of percent correct identifications and RTs are shown in Table 1. As expected, subjects performed the best with the side orientation. As can be seen in Table 1, performance for each target was the best when it was presented in the side orientation, probably as a consequence of the greater size and observable details in the image. Performance measures for the front and rear orientations were similar and considerably worse than for the side orientation especially in terms of RTs.

Table 1

Percent Correct Identifications and Response Times as a Function of Target and Orientation

	Percent correct				Response time (sec)			
Target	front	side	rear	average	front	side	rear	average
British	64	91	73	76	3.0	1.8	2.6	2.5
United States	74	77	75	75	2.5	2.4	2.7	2.6
Soviet	69	80	70	73	2.6	2.1	2.6	2.4
Israeli	83	88	73	82	2.5	1.8	2.8	2.4
Average	73	84	73	76	2.6	2.0	2.7	2.5

Results from the target analyses were complex. Therefore, only a brief synopsis of the results is presented, with the complete statistical analyses contained in the appendix. As shown in Figure 4 (percent correct identifications) and Figure 5 (RTs), performance with a particular target varied greatly depending on both the resolution and range at which the target was presented. For the near range targets, the percent targets identified was very similar for each of the tanks viewed using all resolution levels except the lowest. Responses were significantly faster for the Soviet tank at two resolution levels, 64 and 48 Hz. With the lowest resolution condition, performance was significantly different with the four tanks. The Israeli tank was identified significantly faster and with fewer errors than were the other tanks, while performance was the worst with the Soviet tank. At the far range, RTs to the Soviet tank were the fastest at the high resolution (128 Hz) conditions, while responses to the Israeli tank were fastest at low resolution (32 Hz). However, collapsing across all orientations, ranges, and resolution levels, performance was best with the Israeli tank (see Table 1).

A serendipitous finding emerged from the target analysis concerning the apparent difficulty subjects experienced with the U.S. tank. Collapsing across all orientations and ranges (see Table 1), subjects required the longest time to identify the U.S. tank; only the Soviet tank was identified less frequently. Although performance was the best with the side orientation, the U.S. tank ranked last in both percent correct identifications and RTs at this orientation. Subjects had difficulty identifying the U.S. tank using reduced resolution at the far range, exactly the conditions likely to occur in battle.

Contrast Sensitivity and Performance

Two measures of contrast sensitivity were used in the correlations with performance: the Ginsburg CSF Test using the Vistech VCTS 6500 and the CSF measured using the computer and color monitor. None of the 25 Pearson correlations between contrast sensitivity (five levels) using Ginsburg's test and the number of correct identifications with the five levels of resolution were significant. Two of the 30 correlations between contrast sensitivity (six levels) using the computer and monitor and correct identifications were significant ($\underline{r}$ = -.488 and -.516, both significant $p<.05$). Two significant correlations would be expected by chance for 30 correlations at the .05 α level. In addition, Ginsburg et al. (1983) obtained positive correlations between contrast sensitivity and performance measures. Further, examination of the data plots, in conjunction with analyses of each data point's influence on the correlation (Wilkinson, 1988), indicated that a few outliers were producing the negative correlations.

None of the 55 correlations between contrast sensitivity and RTs were significant. Soldiers with greater contrast sensitivity did not identify more targets or respond more quickly using reduced resolution than did less sensitive subjects.

DISCUSSION

Effect of Resolution and Range on Performance

Results from this study indicate that target identification performance is highly dependent on system resolution and range to target. Soldiers' ability to rapidly identify targets on a CRT degrades in direct proportion to loss of resolution or increase range to target. Operators appear to require large, high resolution images for optimal performance. These results are in substantial agreement with Zwick, Robbins, Mastrianni, and Monroe (1990) who

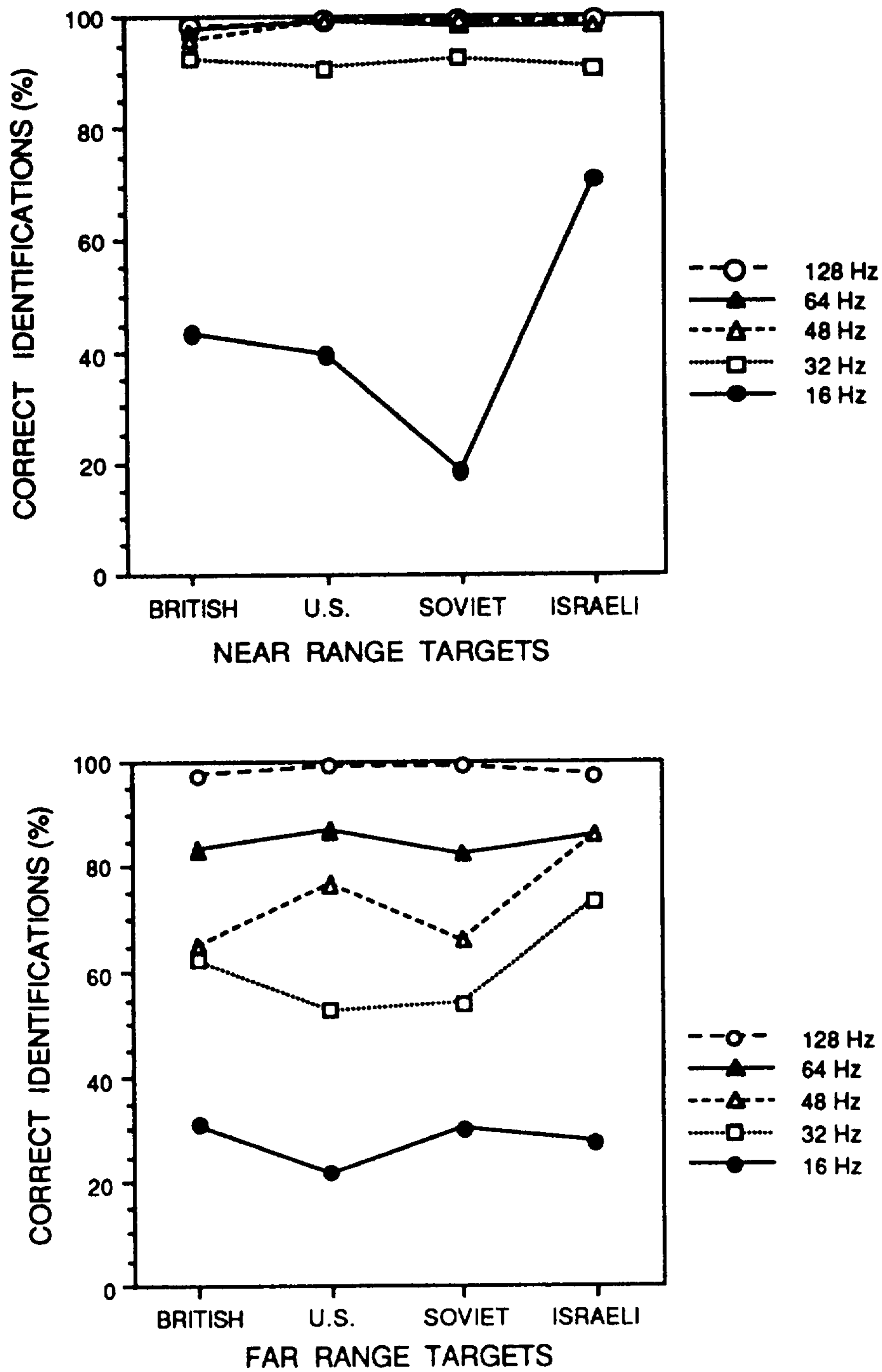

Figure 4. Percent correct identifications by resolution and by target for the near range (top) and far range (bottom).

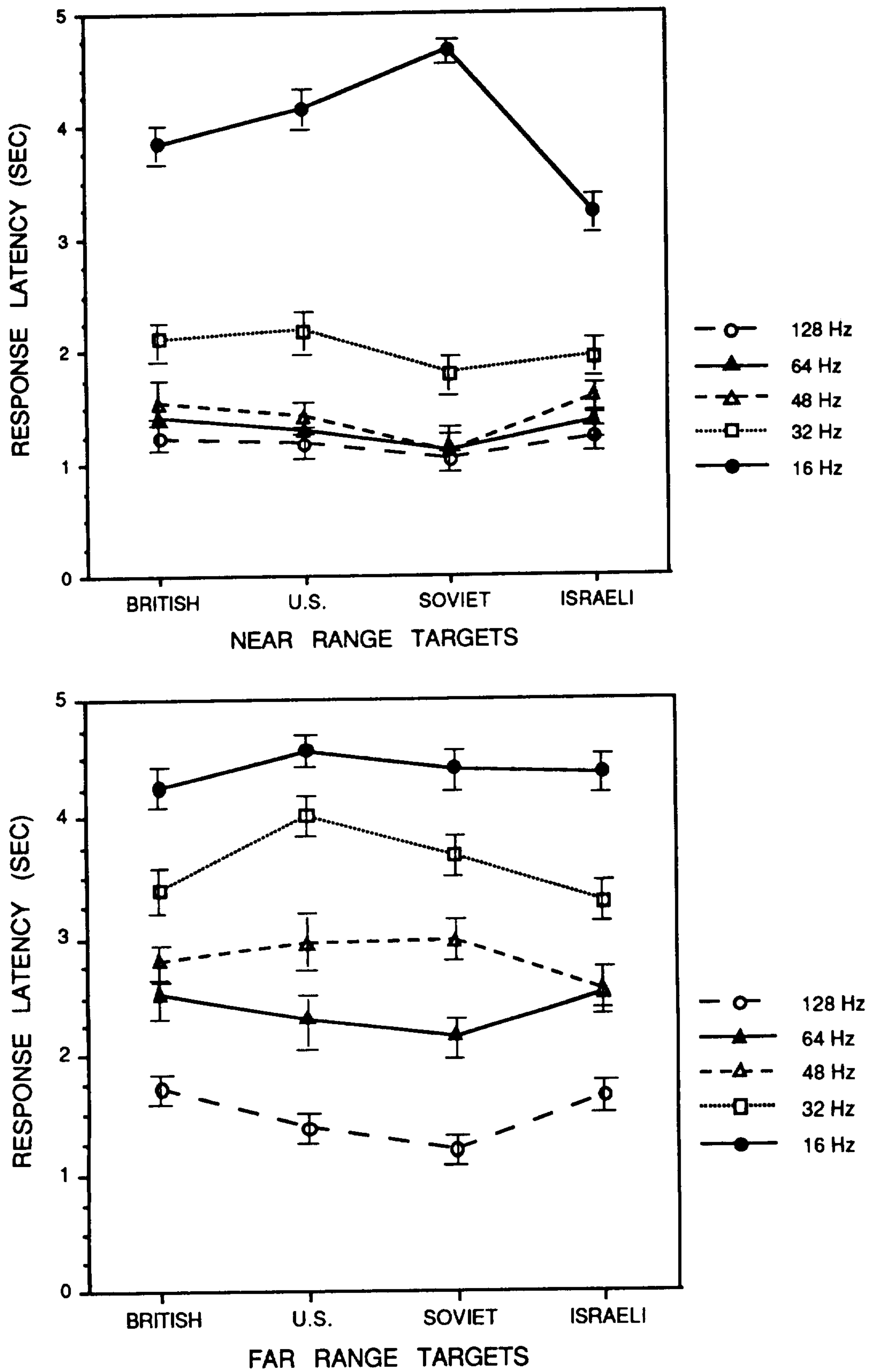

Figure 5. Response latency by resolution and by target for the near range (top) and far range (bottom).

reported a significant increase in target identification thresholds using spatially filtered images. The most interesting and important result from the present experiment concerns the interaction between resolution and range. The effects of resolution on target identification performance were quite different and distinct depending on the range to the target. For the near targets, a moderate to severe loss of resolution had no significant effect on performance. Even when presented with very blurry images, well below the minimum acceptable MTFA, subjects correctly identified more than 92% of the targets. Based on these results, the operator of an ATR does not appear to require a high resolution image as long as the remote sensor can get close to the target (with the important caveats that the target is stationary and has high contrast). This appears reasonable if the sensor is small enough or sufficiently camouflaged to avoid detection. Another possibility would be to magnify the target image presented to the operator. This solution is not entirely satisfactory since magnification amplifies all aspects of the scene including any noise present. Magnification also changes the field of view and may distort depth and range perception. Further studies concerning the importance of range and its interaction with resolution are necessary using a greater variety of stimuli and viewing conditions. It is particularly important to examine forward looking infrared (FLIR) images which are currently used in many weapon systems including the M1, Apache, and the A10. This research effort is essential considering system resolution is such an important and expensive design parameter for future target acquisition systems.

With the far range targets, any loss of resolution always produced a corresponding loss in target identification performance. At the lowest resolution condition, subjects were performing at chance level. Therefore, if the remote sensor cannot get close to the target, soldiers will require a high resolution system to ensure a high probability of target identification and a low probability of firing on a "friendly." With the highest resolution image, results also indicated that range to target had no effect on the percent targets identified. Presumably, with greater ranges to the targets performance would deteriorate. The limiting factor for range appears to be the size of the image on the retina. As range to the target increases, the retinal image decreases in size until at some critically small image, the operator cannot identify the target. Steedman and Baker (1960) reported that visual recognition is independent of target size (range) until the target is smaller than about 12 to 20 minutes of arc. Similar results for target size were reported in three separate experiments by Miller and Ludvigh (1960). Maximum reading rates are also insensitive to letter size until the letters fall below 18 minutes of arc or become so large as to produce limitations because of eye movements (Legge, Pelli, Rubin, & Schleske, 1985). Therefore, for high resolution images, the resolution of the human visual system becomes the limiting factor, and one can conclude that target identification performance is relatively insensitive to target range until the target size falls below approximately 20 minutes of arc.

For all resolution levels except the highest resolution (128 Hz), target identification performance was significantly degraded when subjects viewed the far targets. Why did range affect performance with the low resolution images? One explanation is that the far targets were smaller than the near targets and thus composed of higher spatial frequencies. Therefore, applying a low-pass filter would necessarily remove more high spatial frequencies from the far targets than from the near targets. Since high spatial frequencies (i.e., fine details) are thought to contribute more than low spatial frequencies to target identification (Norman and Ehrlich, 1987), it is reasonable that a low-pass filter applied to a distant target would produce a significant loss in target identification performance. In addition, other perceptual or cognitive factors may affect performance with low resolution, small images. Regardless of the explanation for the phenomenon, one can conclude that for low resolution, indirect viewing systems, the remote sensor must be positioned near the target to ensure optimal soldier-machine performance.

An unexpected and potentially important finding emerged concerning the difficulty U.S. soldiers experienced identifying the U.S. tank especially as range increased and resolution decreased. Operators of an ATR during battlefield conditions must quickly identify distant targets, often using poor quality images. The fact that the U.S. tank is often incorrectly identified during these conditions does not bode well. Certainly, experiences gained in Operation Desert Storm point to the significant loss of lives that can occur because of friendly fire. These considerations underscore the need to improve the discriminability of friendly tanks to minimize the loss of allied equipment and troops.

Visual Functioning and Performance

Standard measures of visual acuity such as the Snellen Test measure a limited portion of visual functioning, essentially the ability to perceive small high contrast images. Acuity tests "are inadequate to evaluate visual capability for target acquisition over ranges of target sizes and contrasts found in operational environments" (Ginsburg, 1981, p. 138). Ginsburg observed that the CSF measures the ability to perceive contrasts over a range of spatial frequencies, and therefore, the CSF rather than acuity tests is operationally relevant to soldiers' performance over a wide variety of tasks, environments, and lighting conditions. In support of this, Ginsburg reported that individual differences in subjects' contrast sensitivity predicted their performance in identifying complex targets including letters and aircraft over a range of contrasts (Ginsburg, 1981; Ginsburg, Easterly, & Evans, 1983; Ginsburg, Evans, Sekule, & Harp, 1982). This line of evidence was pursued in the current study. Since the tanks were low-pass filtered, leaving only the low to mid spatial frequencies, if Ginsburg was correct, subjects with greater sensitivity to these frequencies would be expected to perform better with low resolution images. Unfortunately, individual differences in contrast sensitivity, whether measured by Ginsburg's CSF or the computer-generated CSF Tests, failed to correlate with any performance measure. In Ginsburg's studies of performance in an aircraft simulator (Ginsburg, Evans, Sekule, & Harp, 1982) and pilots identifying actual T-39 jets approaching the runway (Ginsburg, Easterly, & Evans, 1983), the slant range when the subjects first detected the aircraft was measured. In other words, each subject's threshold for detecting a very small, and probably low contrast airplane was correlated with his threshold for detecting several low contrast spatial frequencies. In the present study, the stimuli were all high contrast, large, and well above threshold for detection. The CSF may in fact correlate with performance of visual tasks requiring detection of low contrast small objects rather than identification of large, high contrast objects. Further research appears warranted since the ability to select operators of ATR systems based on their visual abilities would undoubtedly enhance overall soldier-machine performance.

Although the CSF did not correlate with performance, a very interesting finding concerning individual differences in performance was observed. When subjects are required to respond rapidly, there is often a speed-accuracy trade-off, such that fast responses tend to be more inaccurate. However, performance in both the learning trials and the experiment showed a different pattern. Subjects who responded quickly also made fewer errors. Subjects who responded slowly made more errors. These results were based on RTs that used a 5-second data entry for missing responses. Subjects who failed to respond within the 5-second limit would obviously get longer RTs partially because of the increased number of 5-second RTs incorporated into their data. Therefore, the RT data from the experiment were computed without the 5-second penalty for missing responses. In this case, the average time to a correct response was computed for each subject and correlated with his percent correct identifications. These correlations were still highly significant ($p<.01$) for the near targets (r = -.599), far targets (r = -.578), and across all targets (r = -.701). Subjects who identified more targets also responded faster than did subjects who identified fewer targets. For example subject 10, the best subject, identified 25% more targets in 39% less time than subject 16, the worst subject. The soldier who identifies and fires first is likely to survive the battle and contribute to the successful outcome of the mission. These results further support the conclusion that selection of the best operator for an ATR system can significantly enhance soldier-machine performance.

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APPENDIX A

ANALYSES OF RTS FOR RANGE, TARGET, ORIENTATION AND RESOLUTION

ANALYSES OF RTS FOR RANGE, TARGET, ORIENTATION, AND RESOLUTION

Figure 5 shows the mean target identification RTs for the tank targets at each level of resolution for the near range (top) and the far range (bottom). The target identification RTs were subjected to an ANOVA for each level of resolution, with targets and orientation as within-subject variables. Again, the data failed the Mauchly Sphericity Test, so the degrees of freedom for the F tests were reduced based on the Box-Geisser-Greenhouse Index. The Box-Geisser-Greenhouse lower bound F for $\alpha = .05$ is 3.13 for all effects. All Fs that were significant were larger than this lower boundary.

The main effect for targets was significant for all resolutions at the near range, except images low-pass filtered at 128 and 32 Hz. With images low-pass filtered at 64 Hz, the main effect for targets was significant, $F(3,57) = 4.96$, $p < .038$, with mean target identification RTs of 1.42, 1.30, 1.12, and 1.38 seconds for British, U.S., Soviet, and Israeli targets, respectively. Post hoc comparisons of this main effect indicated that the mean RTs for the Soviet tank was significantly different ($p < .05$) from the British and Israeli tanks, and all other comparisons were not significant. Likewise for images low-pass filtered at 48 Hz, targets were significant, $F(3,57) = 9.72$, $p < .006$, with mean target identification RTs of 1.54, 1.42, 1.11, and 1.59 seconds for British, U.S., Soviet, and Israeli targets, respectively. Post hoc comparisons indicated that the Soviet tank was significantly different ($p < .05$) from the British, U.S., and Israeli tanks, and all other comparisons were not significantly different. In addition, the Target x Orientation interaction was significant, $F(6,114) = 10.04$, $p < .005$. With images low-pass filtered at 16 Hz, targets were significant, $F(3,57) = 20.42$, $p < .0001$, with mean target identification RTs of 3.83, 4.15, 4.67, and 3.21 seconds for British, U.S., Soviet, and Israeli targets, respectively. Post hoc comparisons indicated that all targets were significantly different ($p < .05$) from each other, except the British tank was not significantly different from the U.S. tank. The Target x Orientation interaction was significant, $F(6,114) = 11.26$, $p < .003$. Subjects identified the Soviet tank at the near range (see Figure 5) more quickly than the other tanks at all levels of resolution except the lowest level of resolution (16 Hz), where subjects took the longest time to identify the Soviet tank.

At the far range (Figure 5, bottom), the main effect of targets was significant at two resolution levels where images were low-pass filtered at 128 and 32 Hz. With images low-pass filtered at 128 Hz, targets were significant, $F(3,57) = 14.69$, $p < .001$, with mean target identification RTs of 1.72, 1.39, 1.20, and 1.65 seconds for British, U.S., Soviet, and Israeli targets, respectively. Post hoc comparisons indicated that the Soviet tank was significantly different ($p < .05$) from the British and Israeli tanks, and the U.S. tank was also significantly different ($p < .05$) from the British and Israeli tanks. All other comparisons were not significantly different. With images low-pass filtered at 32 Hz, targets were significant, $F(3,57) = 4.56$, $p < .046$, with mean target identification RTs of 3.39, 4.03, 3.69, and 3.28 seconds for British, U.S., Soviet, and Israeli targets, respectively. Post hoc comparisons indicated that the U.S. tank was significantly different ($p < .05$) from the British and Israeli tanks. In addition, the Target x Orientation interaction was significant, $F(6,114) = 4.74$, $p < .04$.

The main effect for target orientation was significant for all resolutions at the near range, except images low-pass filtered at 128 and 64 Hz. With images low-pass filtered at 48 Hz, the main effect for target orientation was significant, $F(2,38) = 12.83$, $p < .002$, with mean target identification RTs of 1.44, 1.23, and 1.57 seconds for front, side, and rear orientations, respectively. Post hoc comparisons indicated that the mean RTs for the side orientation were significantly different ($p < .05$) from the front and rear orientations, and all other comparisons were not significant. With images low-pass filtered at 32 Hz, target orientation was significant, $F(2,38) = 16.34$, $p < .001$, with mean target identification RTs of 2.02, 1.61, and 2.39 seconds for front, side, and rear orientations, respectively. Post hoc comparisons indicated that all mean RTs were significantly different ($p < .05$) from each other. With images low-pass filtered at 16 Hz, target orientation was significant, $F(2,38) = 6.74$, $p < .018$, with mean target identification RTs of 4.09, 3.63, and 4.17 seconds for front, side, and rear orientations, respectively. Post hoc comparisons indicated that the mean RTs for the side orientation were significantly different ($p < .05$) from the front and rear orientations.

At the far range, the main effect for target orientation was significant for all levels of resolution except images low-pass filtered at 16 Hz. With images low-pass filtered at 128 Hz, the main effect for target orientation was significant, $F(2,38) = 32.73$, $p < .0001$, with mean target identification RTs of 1.53, 1.09, and 1.84 seconds for front, side, and rear orientations, respectively. Post hoc comparisons indicated that all the mean RTs were significantly different ($p < .05$) from each other. With images low-pass filtered at 64 Hz, target orientation was significant, $F(2,38) = 36.91$, $p < .0001$, with mean target identification RTs of 2.70, 1.52, and 2.71 seconds for front, side, and rear orientations, respectively. Post hoc comparisons indicated that the mean RTs for the side orientation were significantly different ($p < .05$) from the front and rear orientations, and all other comparisons were not significantly different. With images low-pass filtered at 48 Hz, target orientation was significant, $F(2,38) = 90.51$, $p < .0001$, with mean target identification RTs of 3.51, 1.71, and 3.23 seconds for front, side, and rear orientations, respectively. Post hoc comparisons indicated that the mean RTs for the side orientation were significantly different ($p < .05$) from the front and rear orientations. With images low-pass filtered at 32 Hz, target orientation was significant, $F(2,38) = 25.58$, $p < .0001$, with mean target identification RTs of 3.99, 2.79, and 4.01 seconds for front, side, and rear orientations, respectively. Post hoc comparisons indicated that the mean RTs for the side orientation were significantly different ($p < .05$) from the front and rear orientations.